Opportunities in Mine Water Remediation:

Leveraging Lessons and New Insights in Hydrogeology and Large Plume Treatment

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About ARCADIS

- We provide consultancy, design, engineering and management services, with particular expertise in Water and Environment services
- 19,000 staff in Europe, South America (Brazil, Chile, Peru), Canada, and the US
- Our Mission is to improve the quality of life by creating innovative and enduring solutions that enhance the built and natural environments. By doing so, we produce exceptional value for our clients, employees, and shareholders.
- Our Values

Integrity	**Agility**	**Entrepreneurship**
Client Driven	**Collaboration**	**Health & Safety**

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Mining-Related Services and Capabilities

- Water supply & storage
- Mine water flooding and dewatering
- Water management modeling
- Pit lake management
- Surface water quality
- Stormwater management
- Groundwater plume treatment
- Environmental risk assessment
- Impoundment design
- Slope stabilization
- Geotechnical services

- Demolition and reclamation
- Mine Permitting and Planning
- Heap leach evaluations/optimization
- In-situ mineral extraction

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Problem and Opportunity

- Many mine sites have very large groundwater plumes (sulfate, selenium, arsenic, uranium, etc.)
- Conventional approaches are often containment-based: *No end in sight*
- Experience and new technical developments makes large plume treatment feasible and cost effective

- *Leveraging these advances in plume treatment strategies will result in near-term progress, lifecycle cost certainty, and reduced risk*

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Examples: Large Uranium and Sulfate Plumes

Goal

Protect the environment in a manner that is equitable, requires a reasonable level of short-term stewardship, provides a meaningful near-term risk reduction, is sustainable beyond the timeframe of active intervention, and represents a low risk of failure.

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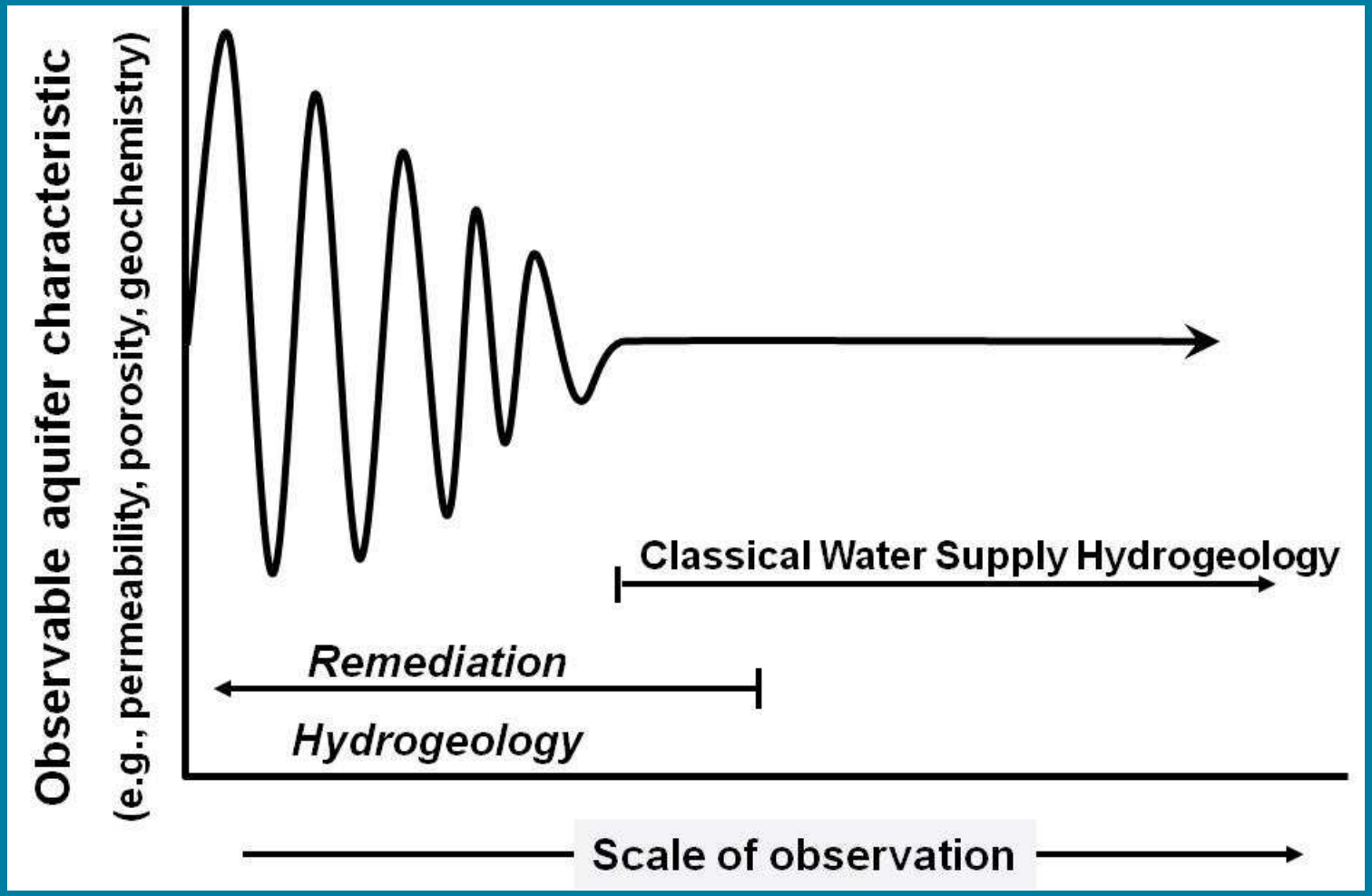
Three Key Elements to Successful Approach

1. Founded on remediation-scale hydrogeology
   - Improved understanding of contaminant transport
   - More successful remediation performance
2. Incorporate in situ treatment approaches
   - Implementation experience well-developed for large plumes
   - New technologies applicable for mining-related constituents
3. Holistic and flux-focused
   - The “Hii” Road: An integrative, prioritized, and adaptive strategy
   - Greatest near-term benefit and overall return on investment

The Remediation Hydrogeology Domain



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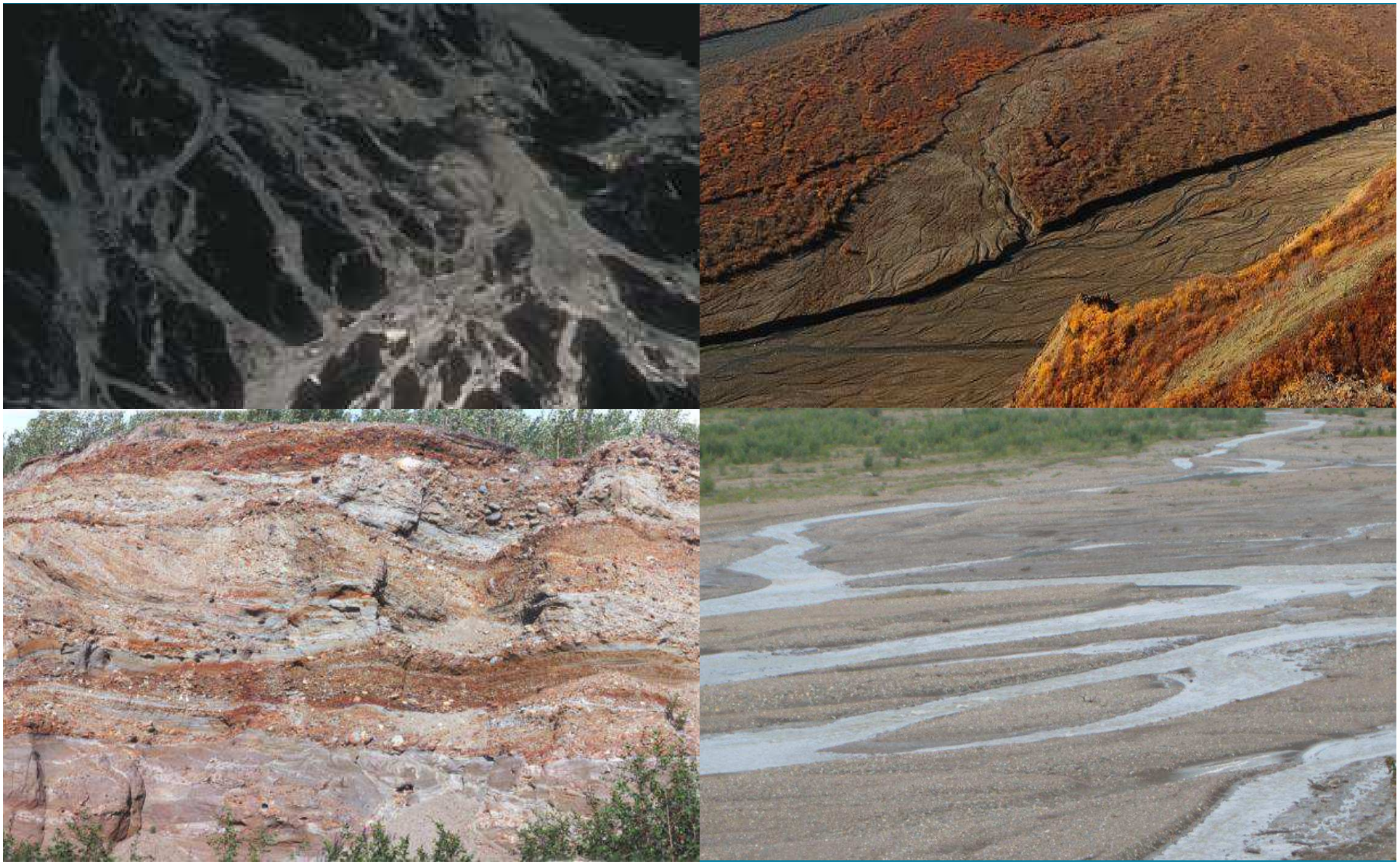
Aquifers are Heterogeneous!



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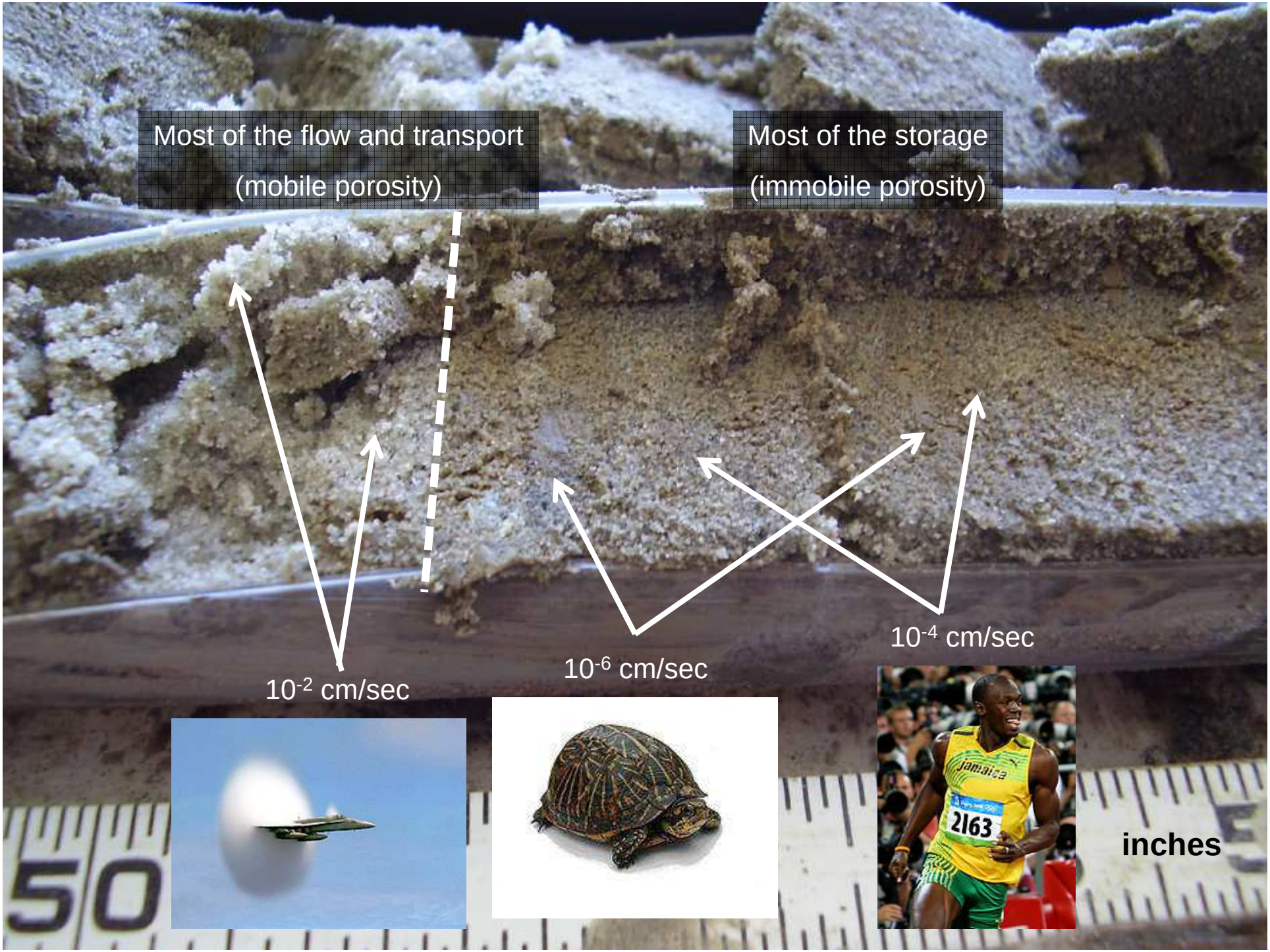
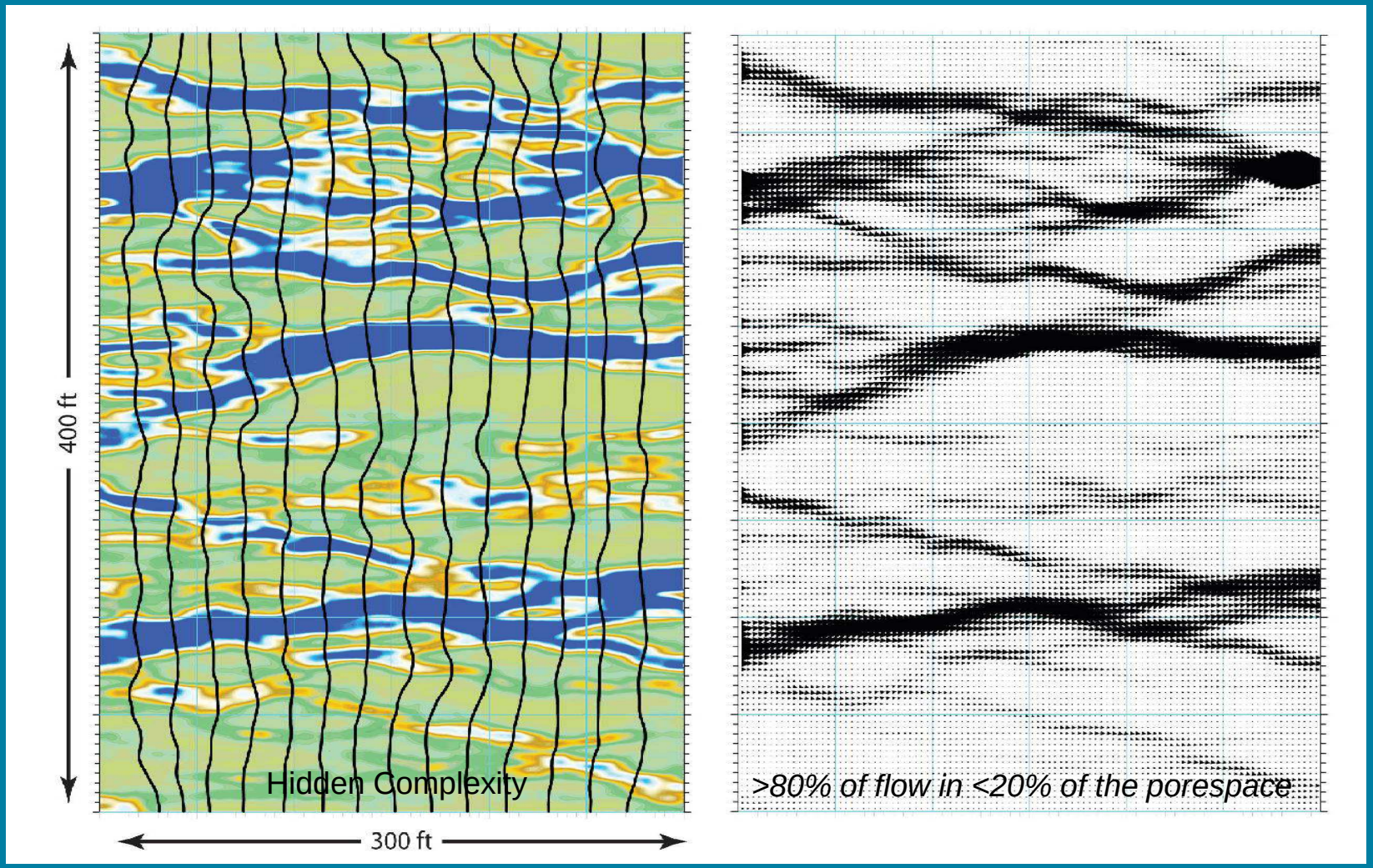

Most of the flow and transport
(mobile porosity)
Most of the storage
(immobile porosity)
10-2 cm/sec
10-6 cm/sec
10-4 cm/sec
Jamaica
2163
inches

Flow Focusing



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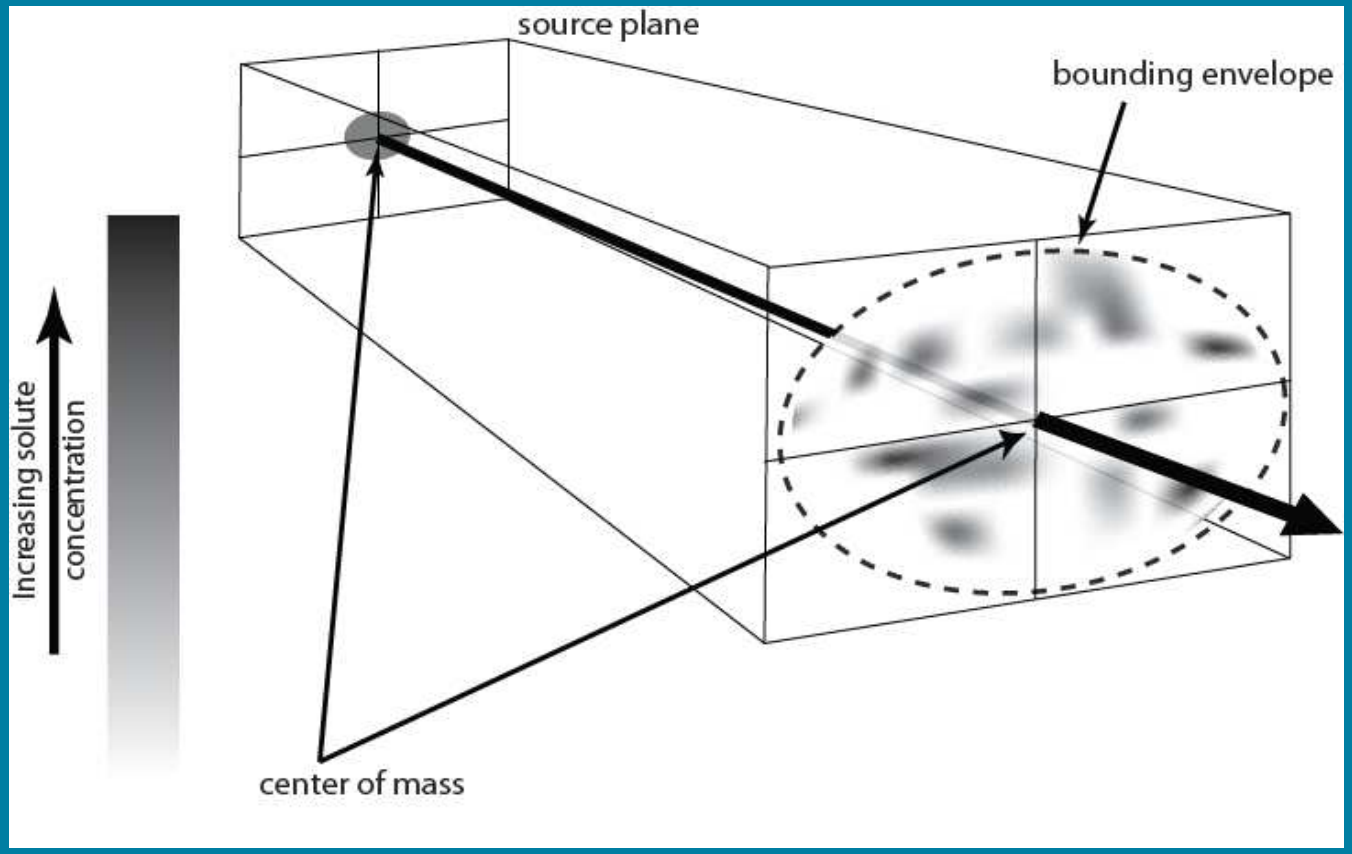
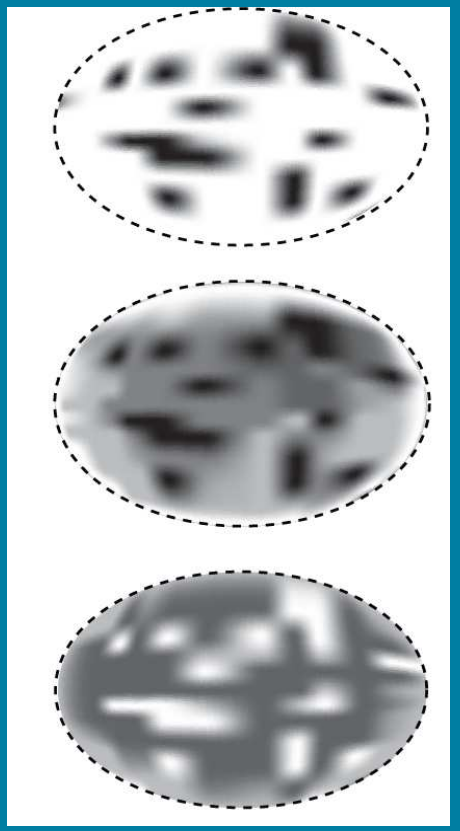
Why Does this Matter?





This conceptual understanding supports <u>targeted</u> treatment of plumes and provides a more reliable prediction on the relative benefits of partial active treatment

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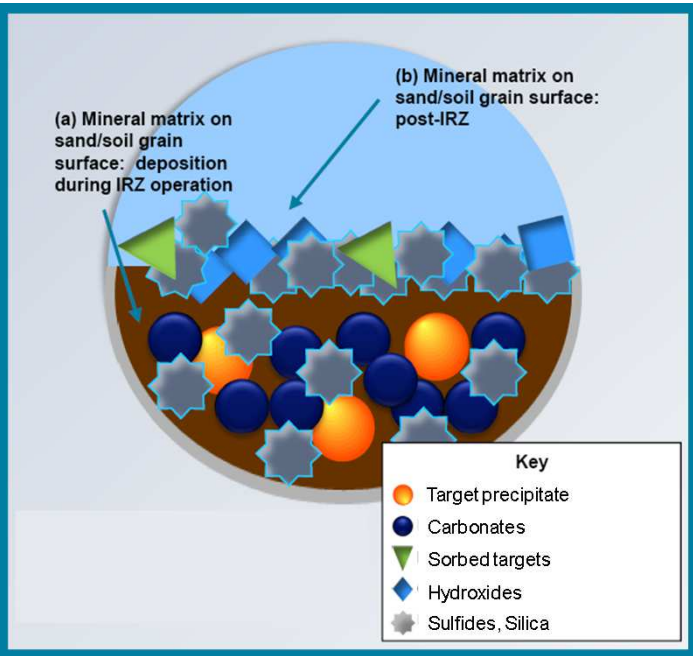
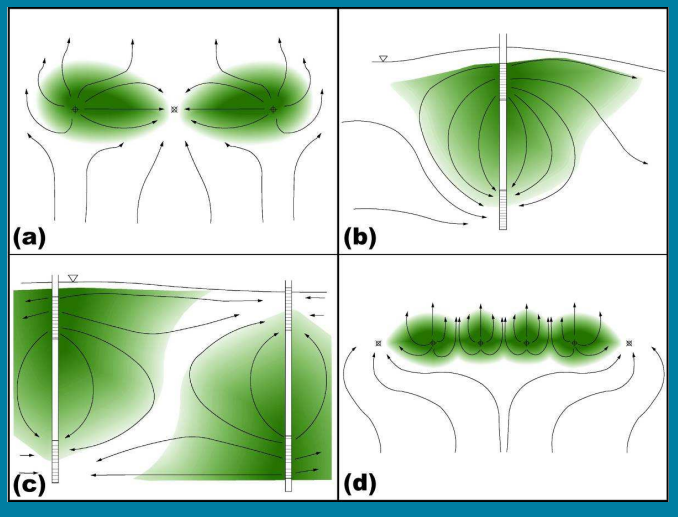
In Situ Treatment Approaches

- Leverage natural biological, geochemical, and hydrogeological processes to facilitate contaminant destruction or immobilization
- Often can provide sustained treatment performance years after short-term activity
- Targeted treatment results in reduced overall remediation timeframes
- Readily incorporated with other approaches
- 15+ years of successfully treating hydrocarbon and solvent plumes
- New technologies applicable for mining-related constituents





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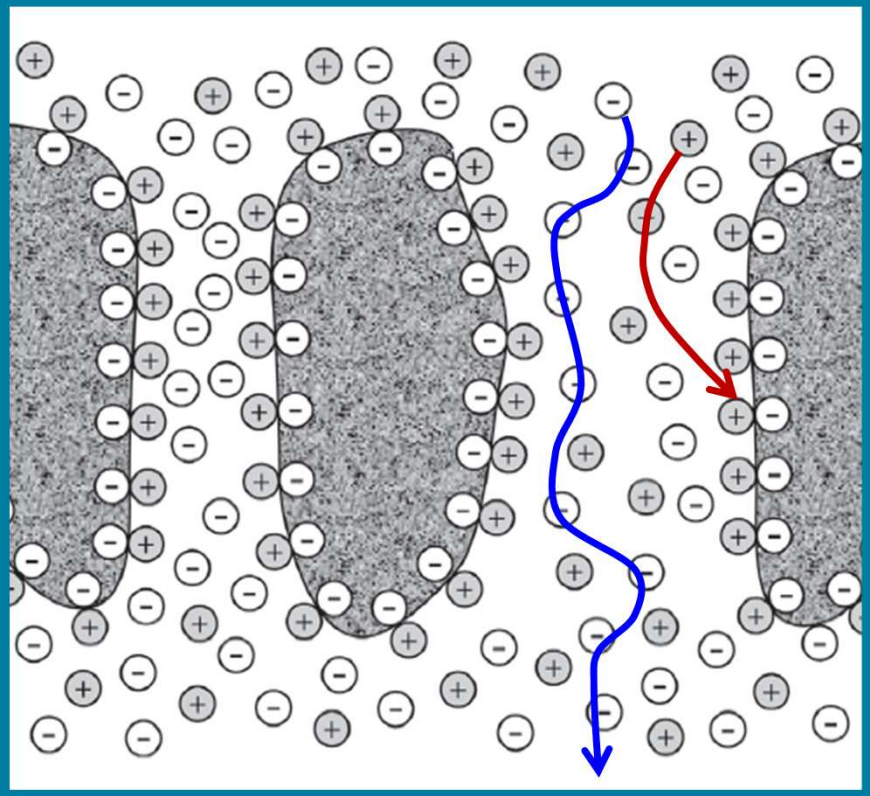
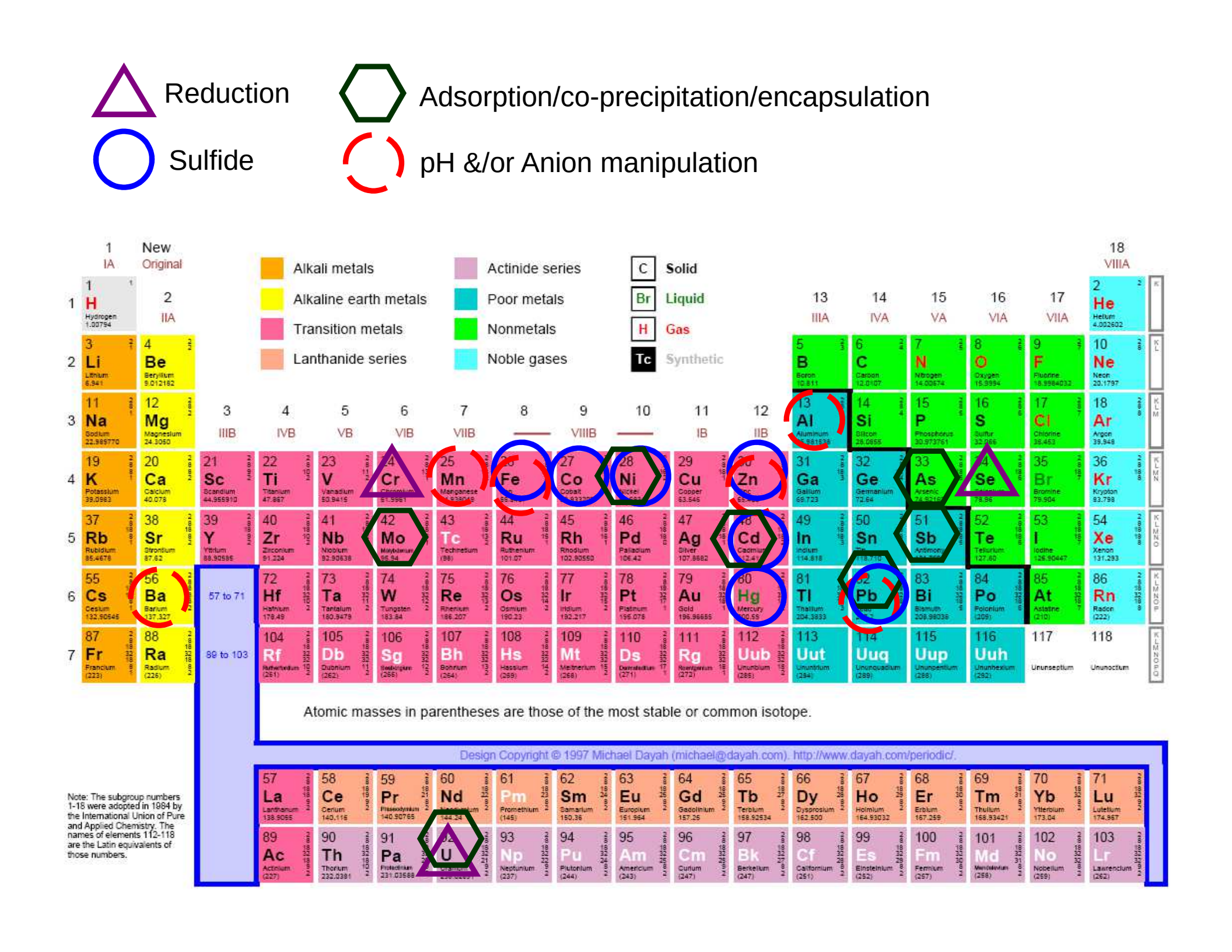
Example: Sulfate

- Common to mines targeting sulfidic ore bodies
  - Liberated during milling and in tailings management
- Mobile and creates large plumes
  - Natural attenuation may not be an option
- Microbially-mediated reduction to sulfide minerals and elemental sulfur

$$SO_4 2^- \rightarrow H_2S + HS^-$$

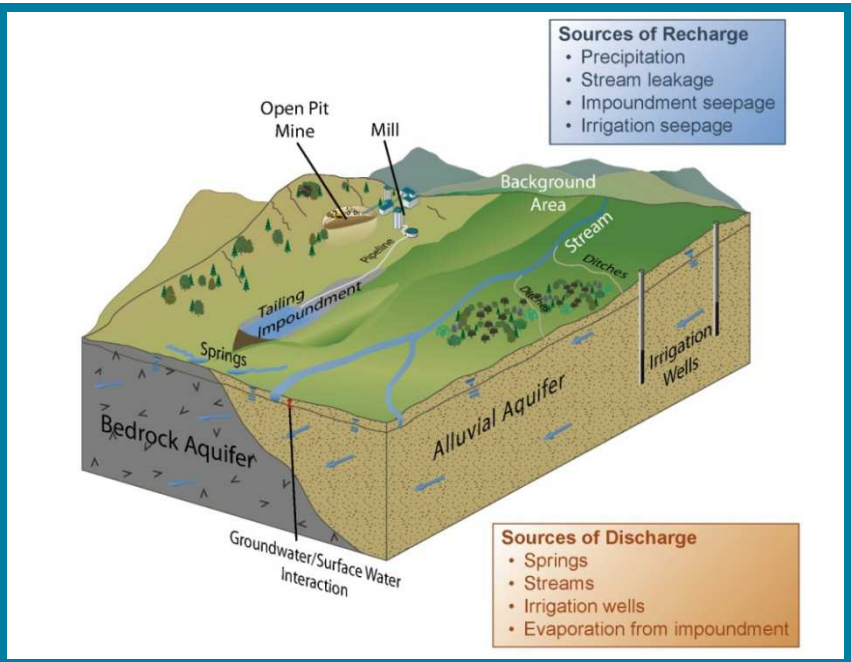
- Precipitates are protected in a matrix of other minerals and remain sequestered

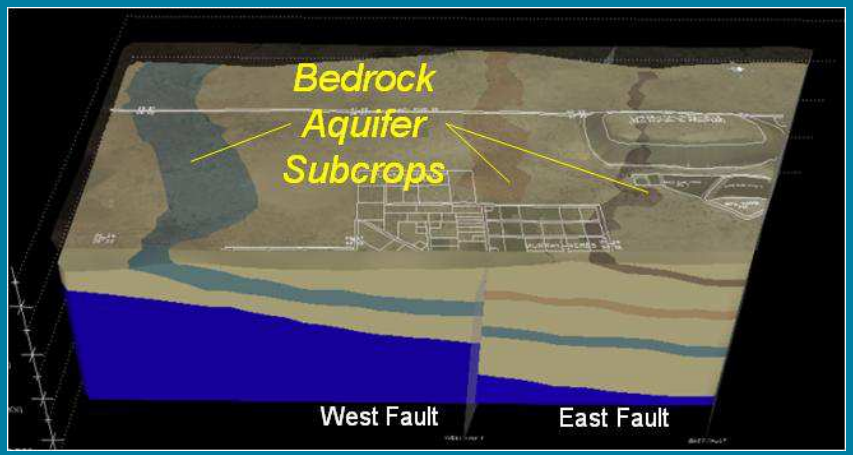



Reduction
Adsorption/co-precipitation/encapsulation
Sulfide
pH &/or Anion manipulation
Alkali metals
Alkaline earth metals
Transition metals
Lanthanide series
Actinide series
Poor metals
Nonmetals
Noble gases
C Solid
Br Liquid
H Gas
Tc Synthetic
Atomic masses in parentheses are those of the most stable or common isotope.
Design Copyright © 1997 Michael Dayah (michael@dayah.com). http://www.dayah.com/periodic/.
Note: The subgroup numbers 1-18 were adopted in 1984 by the International Union of Pure and Applied Chemistry. The names of elements 112-118 are the Latin equivalents of those numbers.

The “Hii” Road

- Holistic Viewpoint
  - Robust Conceptual Site Model
  - Avoid compartmentalization
  - Understand macro-scale interrelationships
  - Identify areas of maximum importance
- Integrated Development
  - Collaborate with mine personnel
  - Leverage work in one area to benefit another
- Incremental Implementation
  - Prioritize emphasis
  - Meaningful progress guided by observation
  - Adapt initial configurations in real time





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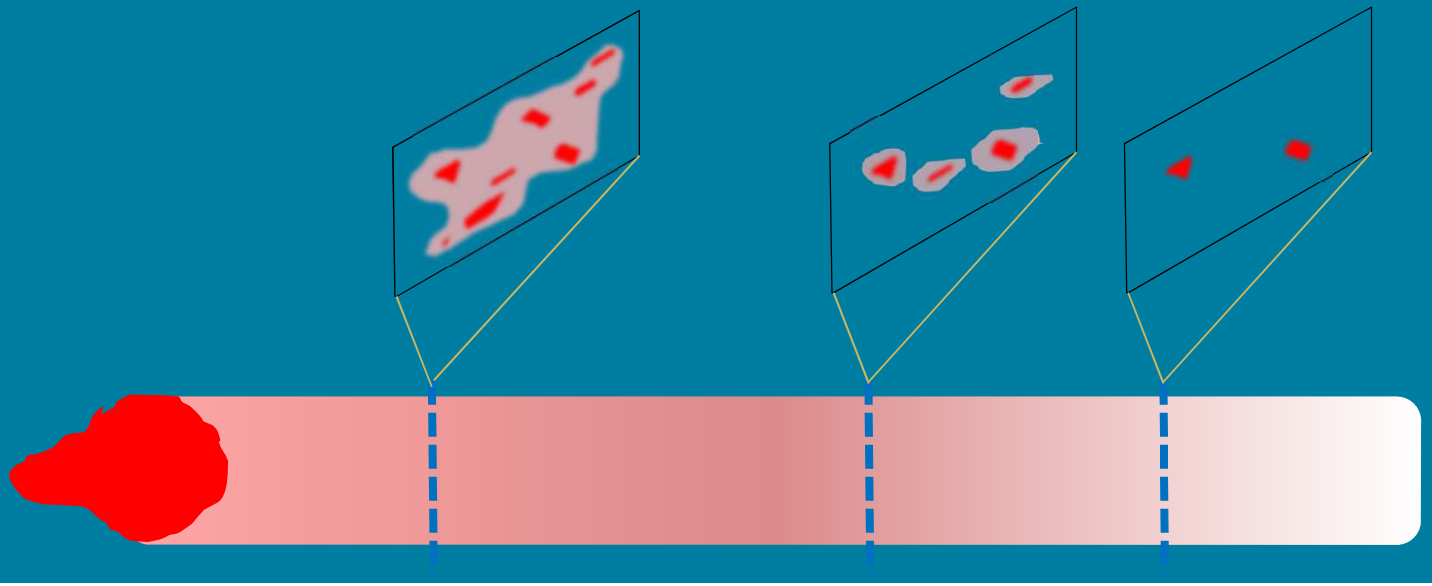
Why Does a Flux-Focused Approach Matter?

- Reality: 80% of flow occurs in 20% of the pore space
  - Not all pores are equal. Focus on the flux!
- Flux controls plume strength and risk
- Largest return by focusing on flux
- Partial source treatment meaningfully reduces risk
- Plume maturity impacts treatment performance



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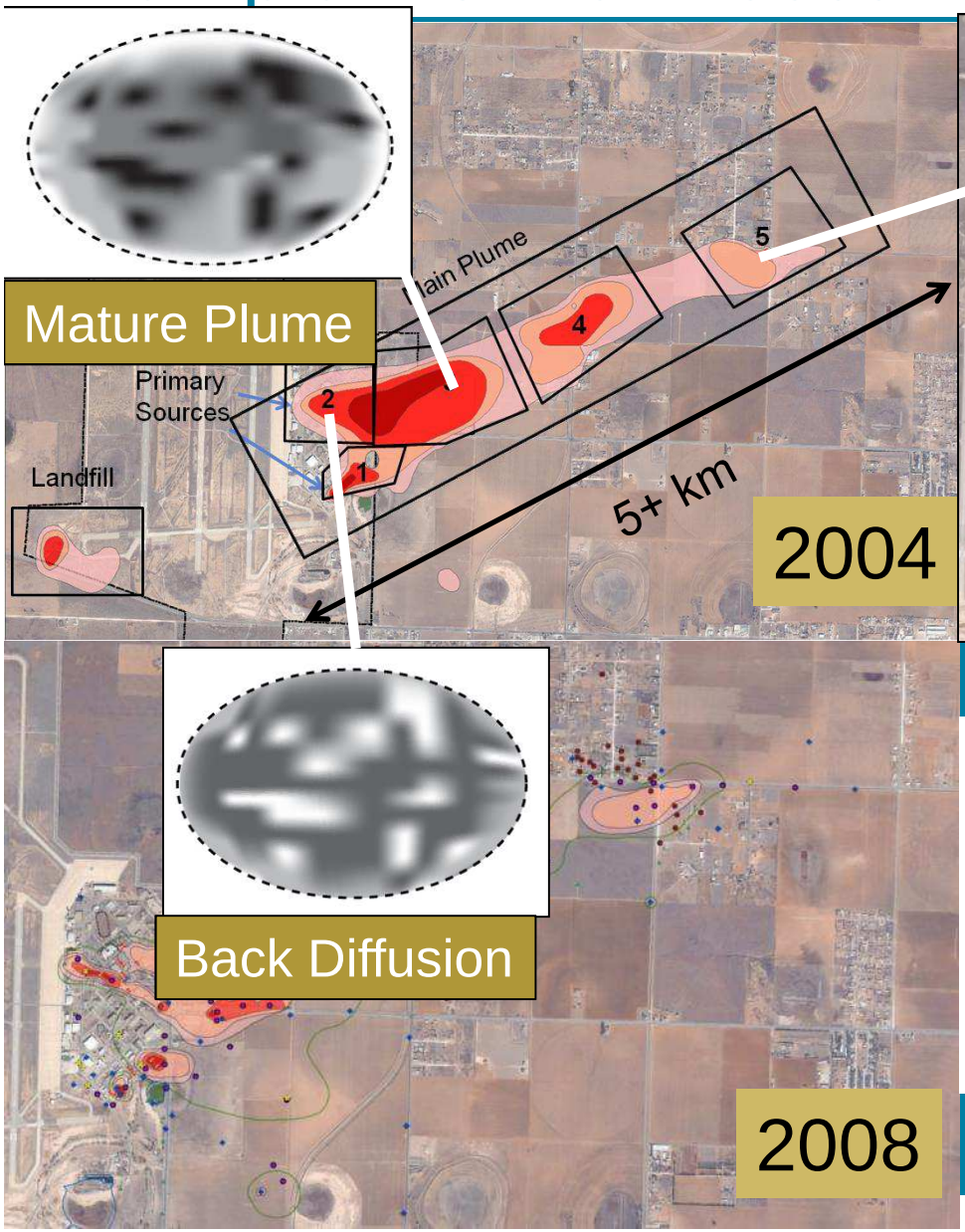
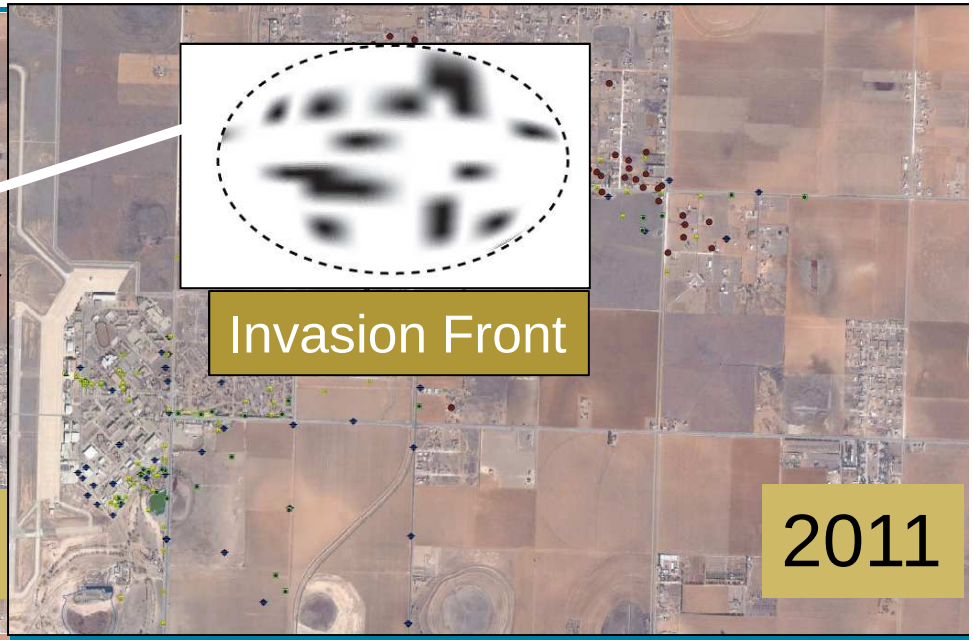
Example: Former Reece AFB





AREA 1 – Directed Groundwater Recirculation (DGR) / IRZ
AREA 2 – DGR / IRZ
AREA 4 – DGR
AREA 5 – DGR
SWLF – DGR

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Example: Former ASARCO El Paso Smelter

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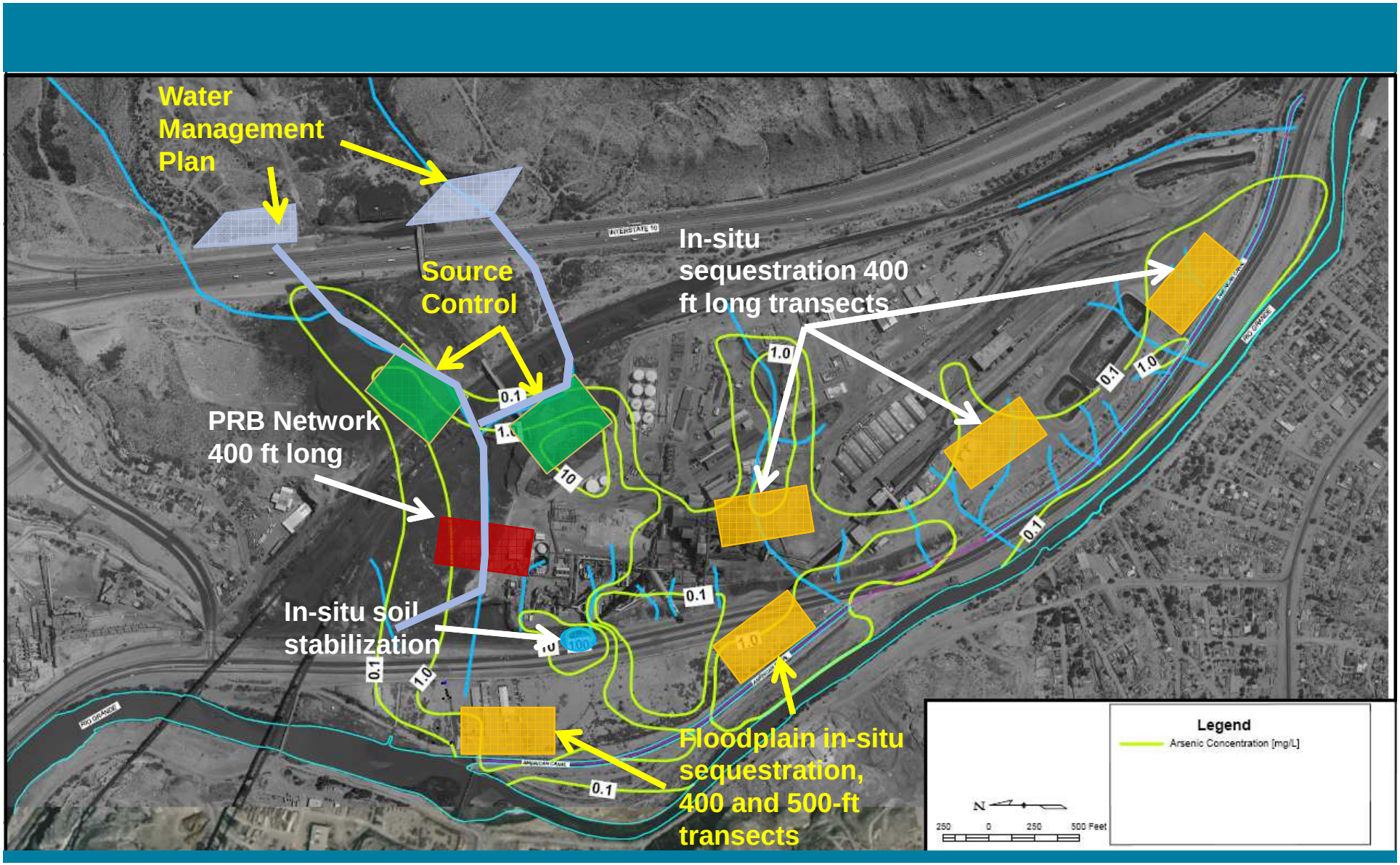
Example: Former ASARCO El Paso Smelter



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Conclusions

Technical advances in remediation hydrogeology and in situ treatment technologies can be leveraged to better address groundwater plumes at mine sites

A holistic and flux-focused approach will compress the overall life-cycle and result in near-term progress that reduces risk, supports an immediate reduction in reserves, and provides the backbone for a sustainable strategy

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